WG2 (Cirrus cloud systems) status and plans

The goal of the Cirrus Clouds working group (WG2) is to improve the physical understanding of cirrus clouds and thereby improve their parametrization in global scale models. The group aims to follow the GCSS methodology of using case studies to compare the performance of high-resolution Cloud-Resolving Models (CRMs) and Single Column Models (SCMs) that use the physical parametrization schemes from full global models. Since the CRMs used for cirrus simulations are somewhat less mature than those used, for example, in the study of boundary layer clouds, we have chosen to conduct some initial model comparisons based on idealized cirrus scenarios. These are intended to identify the major causes of discrepancies between models, their sensitivities to physical parameters whose values are uncertain and to identify an appropriate framework for the future conduct of observationally-based case studies. Two such idealized model comparisons have so far been conducted:

1) the Idealized Cirrus Model Comparison (ICMC), which compares the performance of CRMs and SCMs in situations representative of mid-latitude and sub-tropical cirrus,

2) the Cirrus Parcel Model Comparison (CPMC), which compares the performance of a number of parcel models with fully-explicit microphysics in conditions comparable with the two cases of the ICMC.

A brief description of the results and achievements of these two studies will be given below, followed by a description of the group's plans for the next 12-18 months.

Cirrus Parcel Model Comparison (CPMC)

The models used in this study represent closed air parcels subjected to forced ascent at a range of vertical velocities representative of the range between synoptic scale ascent of a few centimetres per second to convective velocities of around a metre per second such as have been observed in cirrus cloud layers. All models use multiple size bins to describe the size distribution of aerosol particles, cloud droplets and ice particles and have explicit descriptions of the growth of hygroscopic aerosol in supersaturated conditions (including their activation to form liquid cloud droplets) and the homogeneous freezing process. They also have parametrized representations of heterogeneous ice nucleation typical of those used in both CRMs and larger-scale models. The relevance of the CPMC is that a number of the parcel models use identical explicit microphysics to that run in CRMs. Other parcel models are being used to derive improved parametrizations of ice nucleation to be used in CRMs with bulk microphysics schemes. Two main cases have been run; a "warm" case to simulate mid-latitude cirrus formation at around -40C and a "cold" case to simulate sub-tropical cloud at around -60C.

In Phase 1 of the CPMC, each model used its original specification of the homogeneous freezing rate. All six models produce a similar sensitivity of the ice crystal number to parcel vertical velocity, but there is a range of a factor of up to 25 in the final number nucleated. Examination of the results identified two main causes for the variation between models; (i) treatment of the solute concentration impact on homogeneous freezing, and (ii) the use of widely differing values of the water vapour deposition coefficient. Models, using a fixed value for the latter, showed much better agreement in predicted number concentrations. A paper describing Phase 1 of the CPMC is now in press (Lin *et al.* 2002).

Phase 2 of the CPMC examines the sensitivity of the different models to changes in the aerosol inputs, using fixed values of the deposition and condensation coefficients. Five (5) different aerosol size spectra were used as model inputs. Results from this study continue to indicate that inter-model differences in the representation of homogeneous freezing remain the dominant cause of uncertainty in predicted ice number concentrations.

Idealized Cirrus Model Comparison (ICMC)

The ICMC was established to address three key aims in the comparison of cloud-resolving simulations of cirrus; (i) to determine what level of microphysical complexity is necessary to correctly represent the processes occurring in these clouds, (ii) to examine the interactions between microphysical processes, radiative heating and turbulence, and (iii) to examine the impact of key physical properties of the cirrus ice crystals, in particular their fallspeed, on the evolution of the simulated clouds. Temperature and humidity profiles representing similar "warm" and "cold" cases to those of the CPMC were specified. Each simulation proceeded for four hours of simulated time after which the imposed cooling was turned off. The simulations then proceeded for an additional two hours to enable assessment of the cloud dissipation phase of cloud life-cycle among the models. This is a critical issue in that cirrus clouds are commonly observed to be long-lasting.

Fourteen (14) different CRMs participated in the ICMC, generating a considerable spread of values in basic results such as the time of onset of cloud formation, the integrated ice water path (IWP), the shape of the mean ice water content (IWC) profile, and cloud base and top altitudes. Further analysis has, however, begun to clarify some of the causes of these differences.

As anticipated, the representation of ice particle fallout has a major impact on model evolution. The models are initialised with a 1 km deep layer with temperature profile that is stable to ice-saturated ascent and is supersaturated with respect to ice. Models that generate higher ice particle mean fallspeeds tend to precipitate more ice into the subsaturated region below. Evaporation of this ice humidifies the initial sub-cloud layer and leads to a lowering of the cloud base, but reduces the IWP below that of models with low (or zero) ice fallspeed. Such models tend to have IWC profiles that peak close to cloud-top and also a higher intensity of radiatively-driven turbulence. Simulations were also performed with fixed ice fallspeeds (of 0.2 and 0.6 m/s) that span the range of values produced by the models' native representations of ice fallout. This promotes some convergence in model behaviour, in terms of the IWC profiles and time evolution of IWP and cloud base.

Differing representations of ice nucleation behaviour also have a significant impact on model evolution. Those models that describe the homogeneous freezing of aerosol haze particles delay the formation of cloud by up to 90 minutes compared to models which use either parametrized heterogeneous IN or adjustment to ice saturation to prescribe the initial ice cloud. This delay during the period when the model continues to be forced by the imposed cooling results in a larger release of latent heat at first cloud formation and a period of more intense turbulence.

Plans for 2002-2003

Phase 2 of the CPMC and the ICMC will both be written up for publication. From discussions during the GCSS/ARM workshop at Kananaskis, it was apparent that the issue of heterogeneous ice nucleation was of considerable interest to other GCSS WGs. For example, the poor performance of parametrized representations of heterogeneous IN was apparent in simulations of Arctic clouds reported by Judy Curry (WG5). The common behaviour of many GCMs in producing a deficit of medium level clouds of medium optical depth may also be related to a tendency of parametrized IN schemes to promote excessive glaciation of such clouds, and hence the rapid precipitation of cloud condensate. Consideration will be given to extending the CPMC to examine heterogeneous IN activity in the temperature range warmer than about -35C as there are a number of parcel models well-placed to examine these processes in the light of new laboratory and field observations.

The writing-up for publication of the existing ICMC study will be completed before the end of 2002, to include also a general description of the behaviour of SCMs. Whilst this documents the range of model behaviour in response to simple forcings and sensitivity tests, it is unconstrained by observational inputs. Therefore, there remains a desire to complete an observationally-based case study. The "Hurricane Nora" case of 26 September 1997 observed at the ARM SGP site remains the favoured candidate for this due to the extensive observational analysis that is now available (Sassen *et al.* 2002). It is intended that a full case specification from which CRM/SCM simulations can be run will be made available by October 2002. This will include a more comprehensive specification of model output diagnostics than that used for the ICMC study. The possibility of providing a common description of the radiative heating generated by given profiles of IWC will also be investigated, similar to that used by WG1 in boundary layer cloud simulations. This is intended to reduce the divergence between models that is due solely to their differing treatments of the radiative properties of cirrus cloud particles, but does not preclude the comparison between simulations with the common radiative heating scheme and the models' native radiation schemes.

Since the March 2000 Cloud IOP ARM case will also be the basis of work in other GCSS WGs, there is a desire that case(s) from this period should also be studied by WG2. This will enable results from some of the explicit microphysics models used in WG2 to feed information to the convective and regional scale models used in other WGs. It is envisaged that, initially, work on this case would not be undertaken as a full CRM intercomparison but as an additional item by some of the modellers undertaking the Nora case.

REFERENCES

Lin, R.-F., D.O. Starr, P.J. Demott, R. Cotton, K. Sassen, E. Jensen, B. Karcher, and X.H. Liu, 2002: Cirrus Parcel Model Comparison Project. Phase 1: The critical components to simulate cirrus initiation explicitly. *J. Atmos. Sci.*, **59**, 2305-2329.

Sassen, K., W.P. Arnott, D.O'C. Starr, G.G. Mace, Z. Wang, and M.R. Poellot, 2002: Midlatitude cirrus clouds derived from hurricane Nora: A case study with implications for ice crystal nucleation and shape. *J. Atmos. Sci.*, (in press).